OVERSIZED RF WINDOWS WITH TRAVELING *H*-WAVES IN THE DIELECTRIC AREA

V.D. Shemelin
Budker Institute of Nuclear Physics, Novosibirsk, Russia

INTRODUCTION

By output of power about 100 MW from RF generator the problem of strength of output windows arises. To diminishing the power density an oversized window was proposed, i.e. the window with a diameter of several wavelengths [1]. A window with a traveling wave in dielectric [2] was not realized as yet in oversized systems in a pure form because of presence of higher order modes (HOMs). In the oversized window developed in KEK [3], «the quasi TW-mode solution» was realized. One can use higher order modes for decreasing fields in the ceramic-metal brazing area [4]. In the proposed solution there also exists an impurity of a standing wave in the ceramic region.

Nevertheless, the possibility of one-mode regime in the oversized waveguide exists. The trivial solution is a smooth cone taper that does not produce HOMs but it is unacceptably long. In the present work the windows are considered that include a step adapter from one-mode channel (∅30 mm, 11.424 GHz) to the oversized one (∅81 mm), such that amplitudes and phases of the higher order modes in ceramics (ε = 9.3) may be predetermined.

1. OVERSIZED WINDOW WITH ONE OPERATING MODE

1.1 STEP ADAPTER

If one launches the dominant wave from the side of a smaller diameter (Fig. 1), the propagating higher dipole modes can be excited at a larger diameter. One can try to reduce their amplitudes to zero by choosing sizes of steps. So, the radii and lengths of the steps are the variables, and the sum of powers contained in HOMs is the goal function. By specified diameters of input and output, it has been possible to put the sum of HOMs power down to –50 dB relative to the input power. A reflection of the dominant mode from the adapter obtained in the process (r = 0.275) can be compensated by disturbance, for example, by a groove in the one-mode channel. The calculation was done using numerical-simulation code COAX [5] that takes less than 1 s to calculate one version of the geometry with Pentium 120.

The search of the optimal geometry was done without taking the roundings of right angles of the adapter into account. To diminish the local field, the inward projecting angles should be rounded. For the found geometry the roundings were simulated using the same COAX code: by dividing into smaller steps. Then the same calculation was performed by the HFSS code [6] for the rounding radii of 1 mm.

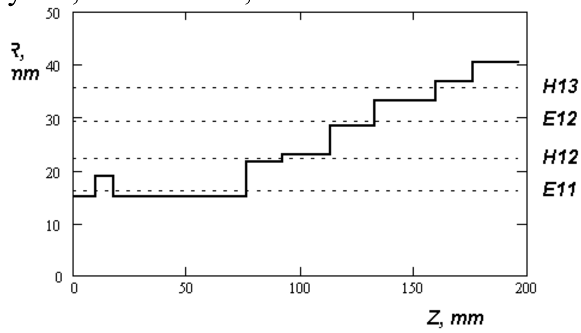

Fig. 1.Step adapter from one-mode channel of ∅30 mm to ∅81 mm.

In Fig. 2, *A* stands for a share of the input power transformed into higher order modes. One can see that failure to take account of the roundings is essential at the maximum compensation only of the HOMs.

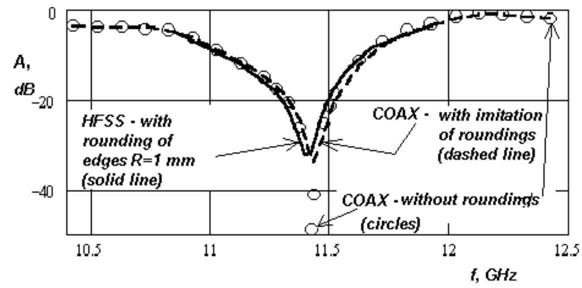

Fig. 2. Content of HOMs at the output of the step adapter.

The presented results demonstrate a possibility to realize an adapter to an oversized diameter by a relatively short length without an excitation of HOMs. The COAX code provides a sufficient accuracy for the axially symmetric geometry. It is necessary to calculate the goal function many times through a process of optimization, so the fast code is irreplaceable.

1.2 MATCHING THE ADAPTER WITH A DIELECTRIC-FILLED WAVEGUIDE

Let us unite the step adapter from the bigger diameter side with the same diameter round waveguide filled with dielectric. At the step adapter output there are no HOMs, so the wave reflected by the ceramics does not contain HOMs as well and can be matched by choosing a diameter and a position of the groove in the one-mode channel.

One has to take into account that HOMs for which the output diameter is smaller than the cut-off diameter, can propagate in the dielectric and can be excited there if the distance from the last step to the dielectric is not sufficiently large.

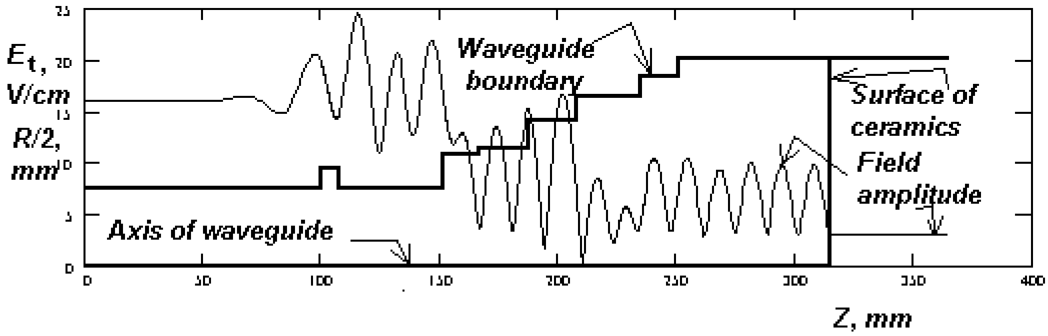

Fig. 3. Formation of the traveling wave in dielectric.

A similar effect should be taken into account when choosing the distance between the matching disturbance and the first step.

On the other hand the indicated distances should be decreased to provide maximum operating band of the adapter.

The builded in such a way structure that creates a traveling wave of the dominant mode in ceramics, and the transverse field amplitude at the axis of this geometry, are presented in Fig. 3. The field calculated for the input power of 100 MW, makes 32 kV/cm in ceramics as maximum (the fields on the graphs are shown for the power of 1 W). This value is much less than 80 kV/cm, taken as a limit for ceramic windows [7]. The field of *H*-waves is tangent to the surface of ceramics. It is possible that the breakdown of ceramics is less probable with this direction of the field. In the presented case the distances between adapter and ceramics and between the groove and the first step are chosen so that the longitudinal field maximum is less than 1.5 % of the maximum of transverse field in ceramics.

The field in ceramics is practically pure H_{11} wave, as it can be seen from Fig. 4. Here the amplitude of the transverse field E_t is shown for two mutually perpendicular radii against the radius, and the longitudinal field E_z, that is formed by residual *E*-modes.

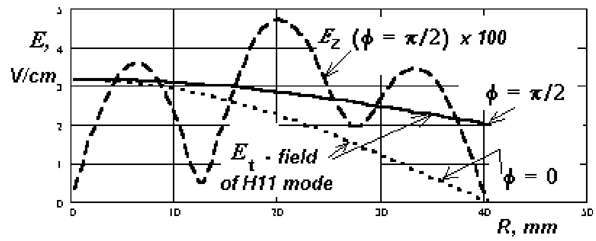

Fig. 4. Fields in ceramics versus radius. The E_z field is scaled by factor × 100.

To construct a window with a traveling wave in dielectric, one has to add to the obtained geometry precisely the same one only rotated 180° relative to the plane parallel to the ceramics surface and going through ceramics. With the disk thickness of $\lambda/4$ the operating band-width is about 60 MHz at the –20 dB level.

2. A WINDOW WITH ZERO ELECTRIC FIELD IN THE BRAZING AREA

For the H_{1m}-waves the fields near the wall of the round waveguide vary in the same fashion: like sin φ (φ is an azimuth angle). So, if the amplitudes of *H*-modes are chosen correctly, and because of their equal polarization, their electric fields near the wall can be done mutually compensated.

Fig. 5. On the construction of goal function for the case of three traveling waves.

To construct the goal function, let us consider the reverse direction of the input waves: let the waves enter from the side of ceramics. Let us prove that if the step sizes are chosen correctly, the reflections of each mode from the ceramics-vacuum interface are either absent or, in general case, proportional to the amplitudes of the incident waves ($\alpha' = k\alpha$, $\beta' = k\beta$, $\gamma' = k\gamma$), see Fig. 5a. As α, β and so on the amplitudes of the corresponding waves are designated.

By changing directions and multiplying amplitudes of all the waves by r, one obtains configuration shown in Fig. 5b. Adding the waves for the cases (a) and (b), and demanding that the leftward waves be compensated, one obtains that there are no reflected waves in ceramics if $k + r = 0$ (Fig. 5c).

So, when constructing the goal function, it is necessary to demand that the reflected *H*-waves are proportional to the incident ones. It is also necessary that amplitudes of the *E*-modes equal zero.

The powers of each of three *H*-modes for the geometry specified in the Introduction are calculated. Phases of H_{12} and H_{13} modes are chosen to be 0 and π,relative to the H_{11}-mode phase. In this case both the modes have the electric field at the edge opposite to the H_{11}-mode field. So, the field in ceramics can be considered as prescribed. It comprises 37 kV/cm in maximum at the full power of 100 MW.

This value is less than in constructions proposed by S. Kazakov [4]: 72 and 57 kV/cm at 100 MW. True, in the cited paper the diameter of ceramics is chosen to be less: two versions - ∅53 and ∅64. But, even taking this fact into account, the relative diminishing of the field in our case (1.54 ÷ 1.95 times) is greater than the increase of diameter (1.27 ÷ 1.53), the longitudinal field is absent and the field at the edge is lowered down not to 10 ÷15 % relative to maximum but practically to zero.

The final construction of the window is to be done in the same way that in Section 1.2: choosing the distances from the adapter to ceramics and to the groove and by reflection of the construction relative to a plane.

3. WINDOW WITH A PHASE SHIFTING OF THE MODES

For the window with three *H* modes discussed above, the modes H_{11} and H_{12} are in phase and the H_{13} is in antiphase to them. A consideration of other relations between the phases of modes does not give any significant decrease of the field because the demand of zero field at the edge is too strongly limiting.

If to abandon this requirement, the calculations show that at the optimal distribution of three *H*-modes in amplitudes and phases for the border diameters and ε, specified above, the maximal field is equal to 27 kV/cm at 100 MW.

CONCLUSION

A method of constructing the adapter from one-mode to oversized waveguide, that creates a prescribed distribution of higher order modes in the output channel, is proposed. Variants of oversized waveguide window with one and three *H*-modes in dielectric are discussed, the modes can be shifted by phases.

Other applications of the method are possible: a construction of the field with minimum losses or with minimum heating of the ceramics, usage of the oversized waveguide without dielectric filling in the one-mode regime as a delay line with low losses, creation of a traveling wave resonator with oversized waveguide i.e. with low losses, or with two or more traveling waves.

REFERENCES

1. V. Balakin. VLEPP Status. Third International Workshop on Linear Colliders (LC91). September 17-27, 1991, BINP, Protvino, USSR. BINP, January 1992.
2. S.Yu. Kazakov. RF Window with TW in Ceramics. Int. Workshop on Pulsed RF Power Sources for Linear Colliders (RF93). July 5-9, 1993, Dubna-Protvino, Russia. BINP, July 1993.
3. Y. Otake et al. High Power Tests of X-Band RF Windows at KEK. Third Workshop on Pulsed RF Power Sources for Linear Colliders (RF96). April 8-12, 1996. Shonan Village Center, Hayama, Kanagawa, Japan. KEK Proceedings, 97-1. April 1997.
4. S.Yu. Kazakov. A Powerful RF Window with a Low Electric Field in Ceramic-Metal Brazing Area. KEK Preprint 98-120, August 1998.
5. O.N. Alyakrinsky et al.. Development of Overmode RF Window Using Multimode Matrix Formalism. Seventh International Workshop on Linear Colliders (LC97). Sept. 29 - Oct. 3, 1997, Zvenigorod, Russia.
6. «High Frequency Structure Simulator», Catalog of Hewlett-Packard Ltd., 1995.
7. Y. Saito et al. Surface Flashover on Alumina RF Windows for High-Power Use. IEEE Transactions on Electrical Insulation, V. 28, No. 4, 1993.